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THE USE OF A MULTI-PROCESSOR MINICOMPUTER FOR COMMUNICATION SYSTEM SIMULATION*

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Abstract

An experimental facility is described which allows new computer communications techniques to be tested under conditions closely approximating those of real systems. A three-processor minicomputer configuration is used to achieve real-time operation at channel transmission rates of up to 50 K bits per second. One processor runs a channel controller-concentrator program, a second is dedicated to simulation of the communication channel characteristics, and the third to the simulation of up to 1000 user terminals. The latter are divided into classes consisting of interactive time-sharing users of differing characteristics and file nodes, mixed in different proportions. Real user nodes are connected to the channel simulator processor, providing experience with actual operating characteristics under different channel loadings. The statistical behavior of the channel is measured by collecting data continuously from selected points in the programs. The channel simulator can be augmented or replaced by connecting an actual channel and associated hardware to I/O ports of the minicomputer, which then connect the user simulator and concentrator programs.

1. INTRODUCTION

One of the problems we have experienced in developing THE ALOHA SYSTEM [1], a computer communications network used for researching new techniques, is that the effort required for hardware and software implementation of the network nodes tends to discourage subsequent changes to the design. Further, many nodes are usually required before the value of the network techniques can be established (or found wanting).

In an attempt to provide a better transition from design to full-scale implementation, we are creating an experimental minicomputer facility (SIMFAC), whose purpose is to allow the network design to be simulated under circumstances as close as possible to that existing in an actual implementation. The following sections discuss the motivation for the SIMFAC, the communications network being investigated, and the SIMFAC design.

2. MOTIVATION

Simulations run on large digital computers are typically used prior to implementation of a new system to evaluate different proposed network designs, but they have many limitations [2], including:

(1) assumptions about network user statistics

(2) omission of system implementation details

(3) lack of real-time user access

The first item is primarily concerned with model-

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ing user behavior with respect to elapsed time between input and amount of input. For human terminal users this is reflected in typing rate, the pattern or grouping of input relative to computer output (the "bursty" nature of human input), and number of characters typed in a burst. This is especially important in THE ALOHA SYSTEM, since it uses a random-access multiplexing technique which is based on the randomness of human time-sharing users.

"Implementation details" refers to the effects on system behavior of factors such as interactions of acknowledgement traffic with asynchronous message traffic in a full-duplex system, finite buffering in network nodes coupled with delays both internal and external to the nodes, and unanticipated limitations due to hardware constraints. For example, the requirement that a node send acknowledgements in response to received traffic might impose significant delays on the sending of message traffic from the node when any economically reasonable implementation mechanism is used. The effects of complex interactions in a large existing network have resulted in deadlock problems which necessitated a redesign of buffering allocation strategies. In general, it is often not possible to evaluate all logical interactions of a system during its design stage, either because of economic considerations or simply a lack of understanding of all aspects of the system (i.e., the system "details").

The third item above means here the inability to experience the network operation in terms of such factors as ease of interaction and delays. This can be important for network design, for example, if the network introduces a randomness to delays which proves annoying or unacceptable to users. (It might be argued that this could be achieved by running a simulation on a time-sharing system and using an interactive console. This does allow user interaction; however, it would be difficult, if not impossible, to separate real-time delays created by the simulated network from those introduced to the simulation program by the time-sharing system.)

The SIMFAC, while still constrained to using assumed statistics for the simulated users, largely overcomes objections (2) and (3). The inclusion of implementation details is easily achieved since, in later phases of THE ALOHA SYSTEM, minicomputers (or in some cases microcomputers) are to be used to interface user equipment to the network (e.g., terminals, large computers). Thus, at least one user node is simply programmed on the simulation minicomputer as if it were being implemented at a remote site, with a terminal interfaced to the terminal control unit (TCU) program in a standard manner. The use of this terminal in conjunction with the requirement that the SIMFAC operate in real time satisfies the third objection, lack of real-time user interaction.

3. THE NETWORK MODEL

The initial effort is concerned with modeling THE ALOHA SYSTEM as a computer network consisting primarily of time-sharing users interacting with one or more large computers, and which uses radio as the communication medium (Figure 1). The network design is based on a multiplexing technique called random-accessing (also known as an ALOHA channel), described in reference [3]. Of concern here is its dependence on the statistics of user interactions and the requirement of a large number of user nodes typically a few hundred, to validate its theoretical expectations (and economic justification). The essential elements comprising the network are (1) the user nodes, (2) the radio channel (in each direction), (3) a single channel controller which regulates traffic in the channel and provides an interface to one or more time-sharing systems, and (4) the time-sharing system(s).

The steady-state behavior of the ALOHA channel (i.e., the traffic flowing from user nodes to the controller) has been estimated analytically as

$$S = Ge^{-2G}$$

where S is the channel utilization (throughput), G is the total traffic offered to the channel, and the total traffic is assumed Poisson distributed [3]. This gives a maximum channel utilization of approximately 1/2e, or about 18%. Traffic from the

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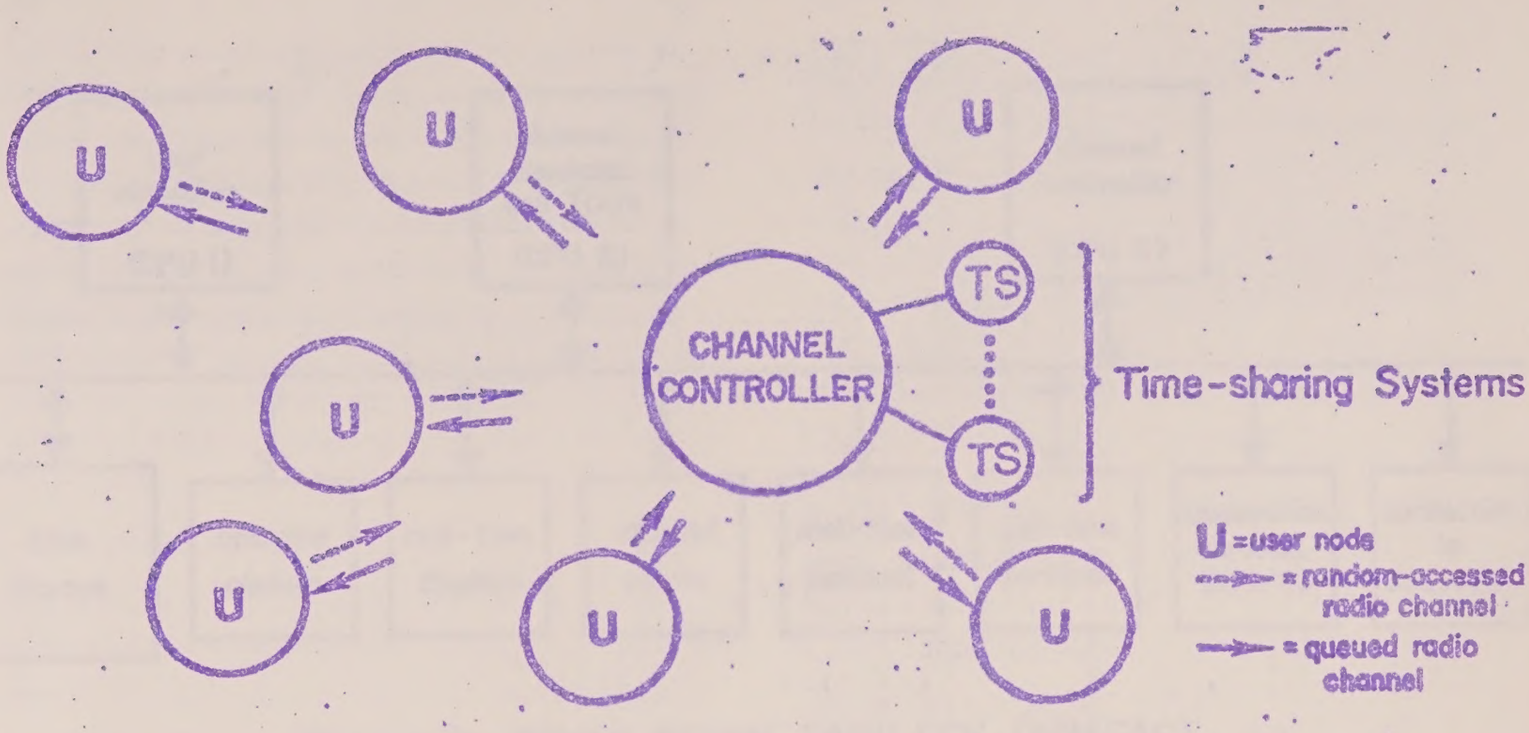


Figure 1 RANDOM-ACCESSED RADIO NETWORK

controller to users is queued in the controller and sent sequentially, allowing 100% utilization of the second channel.

4. SIMULATION FACILITY DESCRIPTION

A block diagram of the SIMFAC is shown in Figure 2. It consists of a Lockheed SUE modular minicomputer (also being implemented as a high-bandwidth node in the ARPANET [4]), with three processors and 20K words of 16-bit core communicating on an infibus. The hardware is designed such that one of the processors intercepts all hardware interrupts generated by I/O devices or system clocks.

To achieve real-time operation at the channel transmission rates of interest (up to 50K bits/sec), one processor is dedicated for use by the channel controller program, one is shared by the channel simulator and TCU programs, and one is used for the user simulator program. Two independent clocks are also provided by a card in an infibus slot, one for each communication channel between the users and the controller. The clock rates are program selectable according to the desired transmission rates; and allow different rates to be used on each channel.

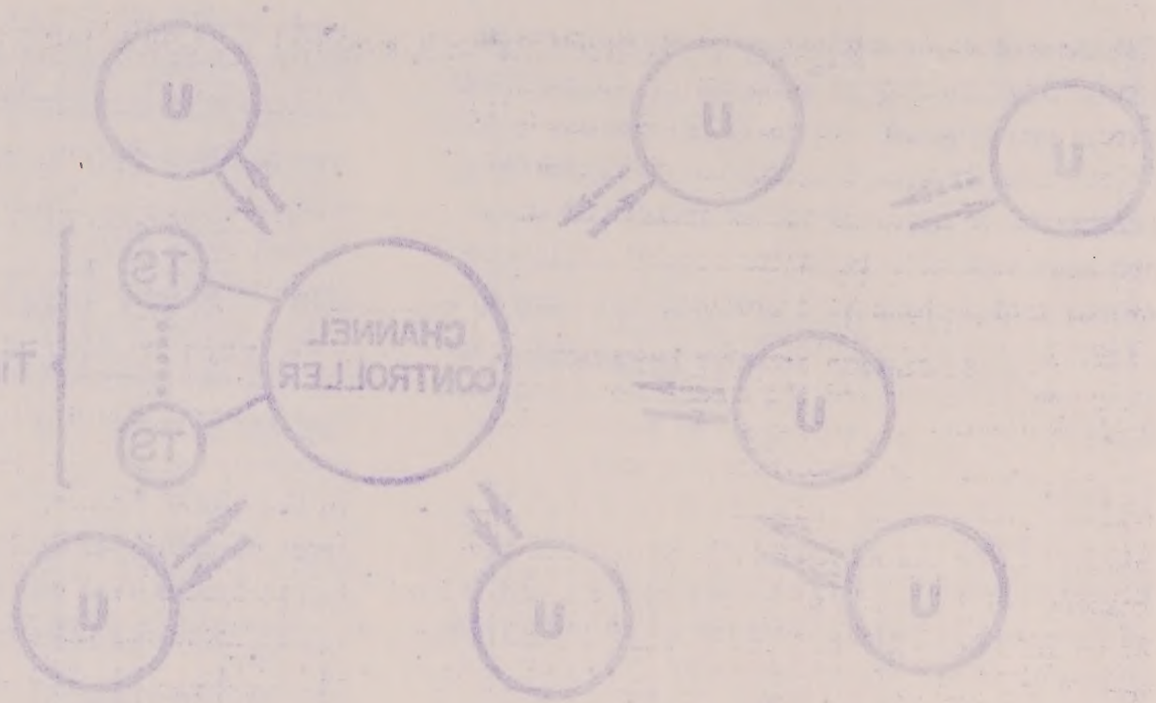
4.1 CHANNEL CONTROLLER

This (and the TCU program) represents the most important aspect of implementation detail achieved in the SIMFAC, since it is programmed to the same level of detail as would be one in a fully operational system (and can in fact be later directly transplanted for use in an operational system if the same type of minicomputer is used). Of direct concern to the evaluation of different multiplexing techniques is the effect of protocol details such as acknowledgement traffic, interactions of user and controller acknowledgement protocol, and effects of controller queues on the channel.

Its implementation includes:

(1) selection of either positive acknowledgement or negative acknowledgement error control schemes

(2) full queuing of all incoming and outgoing messages, including those waiting for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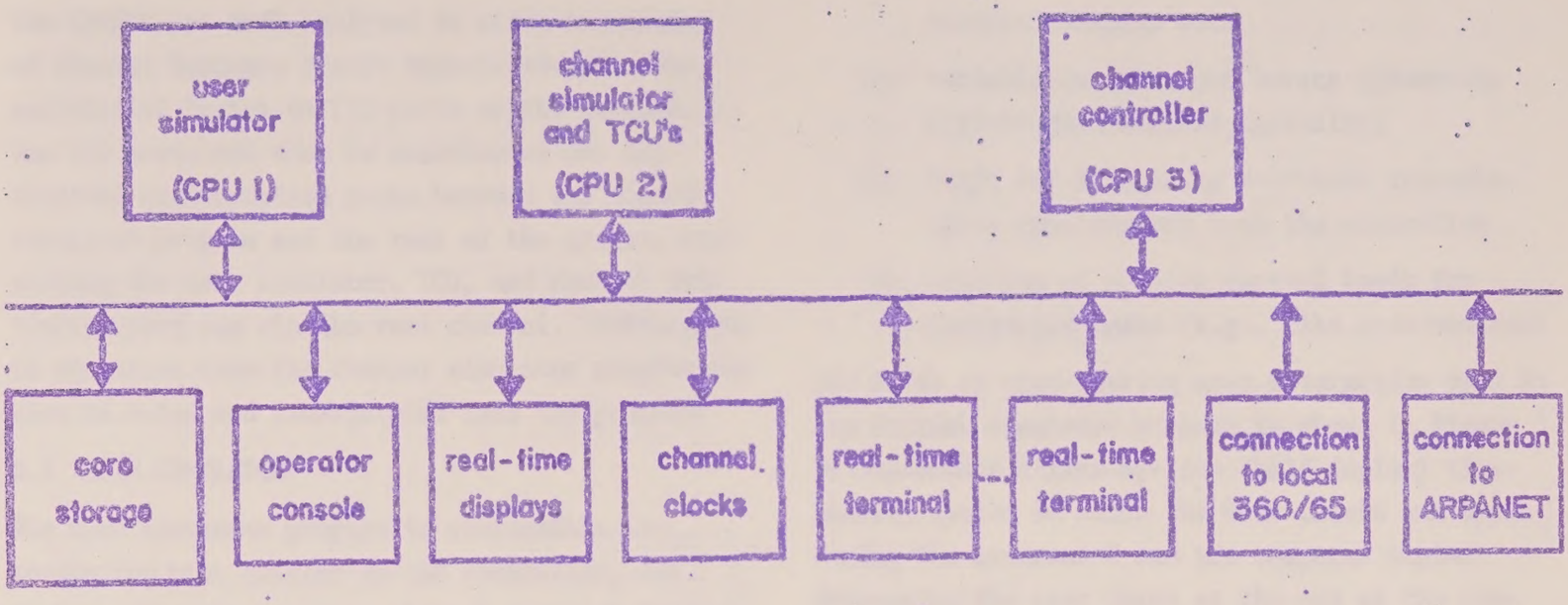


Figure 2 SIMULATION FACILITY (SIMFAC)

acknowledgement

(3) calculation of terminal display times for 110 b/s or 9600 b/s rates (used for flow control to terminal nodes)

The selected error control scheme strongly affects buffer allocation in the controller, since a negative acknowledgement scheme (or a positive scheme using sequence numbers) requires that many unacknowledged packets must be held for possible retransmission. It also significantly affects channel utilization in both directions; positive acknowledgements from terminals degrade the random-accessing channel, while negative acknowledgement schemes require more bandwidth in the channel to terminals.

Terminal display rates have an important effect on the total system, since the display rate of CRT terminals is typically a factor of 10 greater than that of teletypes. This results in more traffic to terminals, a higher user input rate, and increased queuing delays in the controller. The implemented channel controller allows different mixtures of these rates to be assigned, with their effects on the system produced by the actions of the controller.

4.2 CHANNEL SIMULATOR

This program contains knowledge of the channel transmission rates and propagation distances between network nodes, and uses this to convert messages passed to it by the user simulator and controller programs into real-time events at the destination nodes. It also simulates the major elements of channel hardware and physical events which are known to affect network operation, such as FM capture effect in the controller's radio receiver and local noise conditions at each node. It includes:

(1) simulation of packet interferences at the controller input port

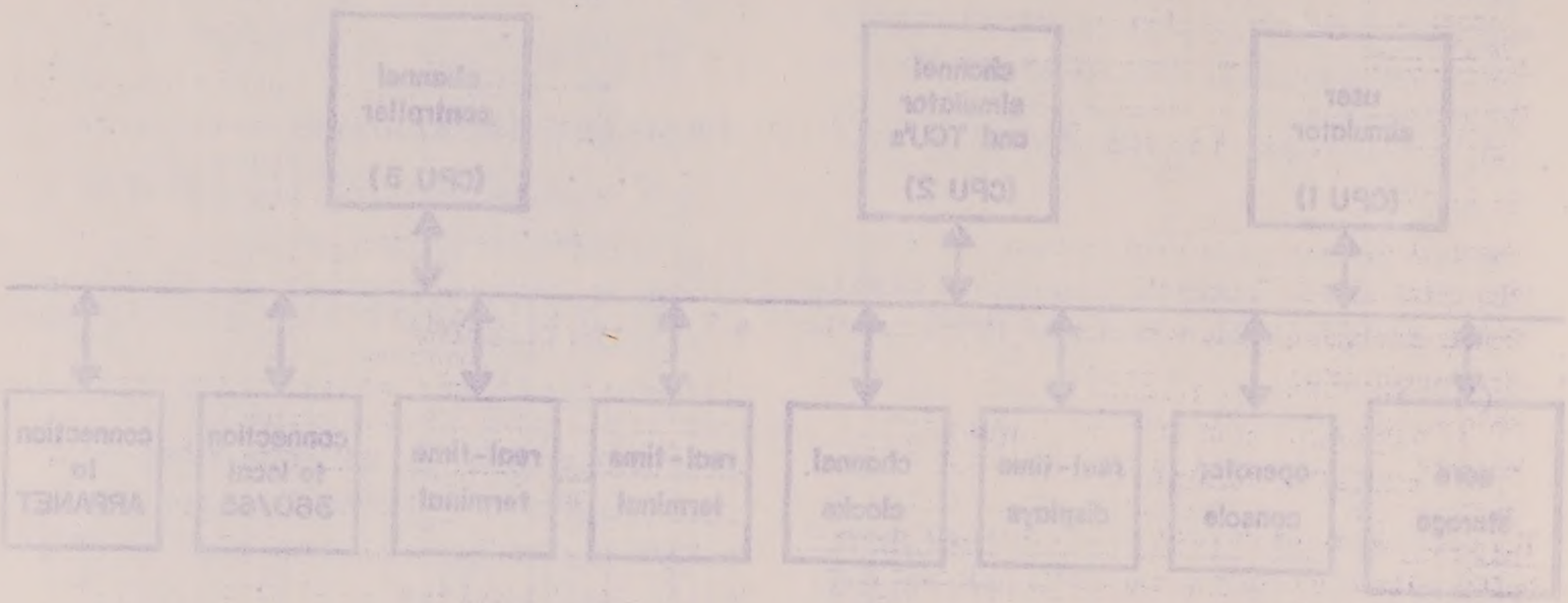
(2) calculations of propagation delay and packet transmission times

(3) real-time interface for input and output to the controller

(4) simulation of FM receiver capture effects

(5) simulation of local noise effects at the controller's receiver

(6) simulation of local noise effects at user node receivers


user simulator (CPU 1)
channel simulator and TCU's (CPU 2)
channel controller (CPU 3)
operator console
real-time display
channel clocks
real-time terminal
real-time terminal
connection to ARPANET

The SIMFAC has been designed to allow connection of channel hardware (radio transceivers, modems, and digital logic) to I/O ports on the infibus. The I/O ports can then be substituted for the internal communication paths between the channel simulator program and the rest of the system, connecting the user simulator, TCU, and channel controller programs via the real channel. Differences in operation from the channel simulator program can then be noted and incorporated into the program.

4.3 USER SIMULATOR

The user simulator program is responsible for generating user traffic to the controller, and implementing the complete channel protocol between each simulated user and the controller (e.g., generation of acknowledgements and retransmissions). It makes certain assumptions about the generation of new traffic from each user, but constrains the actual generation of events in the channel according to feedback from the controller (via the acknowledgement messages). Its features include:

(1) selection of positive or negative acknowledgement error control

(2) designation of up to four different user classes, where each class is represented by a different set of input generation statistics

(3) designation of either 110 b/s or 9600 b/s terminal display rate

(4) variable-length input bursts (geometric distribution assumed initially)

(5) logic for inhibiting user-mode transmissions upon command from the controller

(6) addition of special control logic for designated nodes (e.g., file node control)

The model of time-sharing user interaction used in the initial simulator program is shown in Figure 3. It represents a line-by-line (half-duplex) time-sharing system in which the user thinks and types during the interval T and the computer begins processing the user input at the end of the communication system delay D. After a processing interval C, a sequence of n responses are sent to the user terminal which require display times P_1 to P_n. A new T interval is assumed to begin at E, following the end of the last line displayed.

Two statistical distributions are assumed for each user: the distribution of T, and the number of characters typed during each T interval. Provisions are made for distinguishing up to four different classes of users, representing different distributions or different parameters of the same distribution. The classes can be mixed in specific proportions, allowing in the extreme the designation of all nodes as homogeneous time-sharing users, or at the other extreme as constant-input "file"

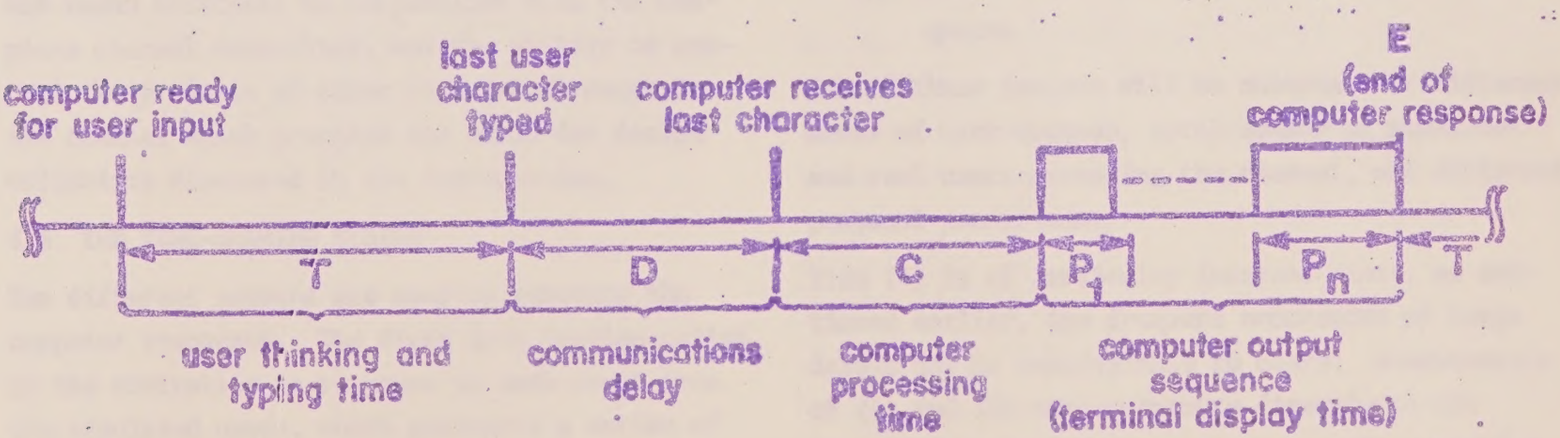
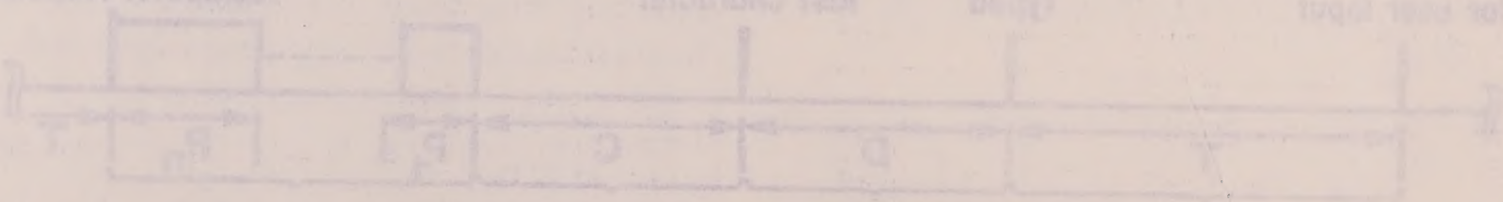


Figure 3 ASSUMED MODEL OF USER INTERACTION



nodes. Each simulated node is represented by table entries and is treated individually with respect to its transmissions and acknowledgements (or retransmissions).

4.4 TERMINAL CONTROL UNIT (TCU)

The terminal control unit program consists of a completely programmed channel interface for a user node. It provides the same protocol interactions to the channel as the user simulator, but in addition represents an attempt to include all functions which might be implemented in a real node, such as:

(1) transparency mode

(2) selection of echoing strategy

(3) full-duplex buffering

(4) display formatting

(5) broadcast message recognition

(6) failure-to-send signal to user

It should be noted that all of the above items, while concerned with user rather than channel considerations, affect the design of channel logic to varying degrees. For example, the provision of a transparency mode affects the design of packet synchronization, while remote echoing can have a significant effect on channel utilization in both directions.

It is this fully implemented TCU (with a terminal and human attached) in conjunction with the complete channel controller, and the ability to control the presence of other (simulated) users in the channel which provides the basis for design validation discussed in the introduction.

4.5 THE TIME-SHARING SYSTEM

Two different sources are used to generate the computer responses. The first is a routine called by the controller in response to each input from the simulated users, which generates a series of responses. Two distributions are used by this routine, one for the computer response delay C and one representing the number of responses (both taken from the data of Fuchs and Jackson [5]).

The second source is a time-sharing system running on a large computer, and is used to generate responses to inputs from the real user(s) on the system. The SIMFAC will be connected to both the local campus 360/65 and to ARPANET, allowing a choice of a variety of different systems. Delays introduced by the time-sharing system are recorded for possible future use by the response simulator routine.

4.6 STATISTICS COLLECTION

All events relevant to system behavior are recorded for subsequent statistical processing. A real-time display is provided by a CRT terminal and digital display devices to infibus ports of the SIMFAC. This allows immediate monitoring of key variables, such as channel throughput, during a run.

The following quantities are of special interest in evaluating the network design:

(1) channel utilization (relative occupancy of good packets)

(2) channel interference (relative occupancy of bad packets)

(3) total channel traffic

(4) distribution of user delay (i.e., probability that a user will experience a given delay per packet)

(5) channel recovery from overload conditions

(6) maximum and average lengths of controller queues

All of these factors will be obtained for different mixes of user classes, total number of simulated and real users accessing the channel, and different protocol conditions.

Item (4) is of particular interest since, as mentioned earlier, too frequent occurances of large delays may be unacceptable to users. Measurements of (5) and (6) can contribute directly to the design of control mechanisms to prevent excessive overload, or to different queuing strategies and maximum message lengths defined in the controller. Of importance is the fact that these changes can be readily implemented in the SIMFAC by substitut-

ing different subroutines in the appropriate program, and new simulation runs immediately made to investigate their performance.

5. CONCLUSION

The SIMFAC is currently being debugged, and is expected to be fully operational within two to three months. One of its first uses will be to explore protocols for mixing file traffic with interactive user traffic in the random-accessing channel, a problem which is becoming increasingly important in the operational ALOHA SYSTEM as the use of tape cassettes and other terminal-oriented storage media increases. Strategies for controlling the rate of file mode inputs will be implemented as subroutines for certain of the simulated users, as designated by table assignments.

An important feature of the SIMFAC will be the continued updating of its assumed statistical distributions to more accurately reflect the real world. Data provided by measurement projects such as [6] is expected to significantly enhance the SIMFAC's usefulness. Some factors of special interest are:

(1) user typing rates

(2) user think times

(3) number of characters typed per burst

(4) effects of display rate on (2)

(5) effects of display rate on the number of lines requested for display by the user

All of these have significant effects on the performance of an ALOHA channel, and are currently reflected in the SIMFAC implementation.

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